GFDL Modeling Activities

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CM2 Model Development

- Two model versions developed
  - CM2.0 and CM2.1
- Atmosphere
  - 2^o,24 vertical levels
  - RAS, Locke PBL, diurnal, ….
  - 2.0="B" grid core, 2.1=finite volume core
- Ocean
  - 1^o, 50 vertical levels
  - Free surface, tidal mixing, tri-polar grid, ….
- Sea Ice
  - Multiple ice thicknesses, complex rheology
- Land Surface
  - Rivers, changing land cover types, …

IPCC Fourth Assessment Report

Keith Dixon

- Accomplishments
- Level of Effort
- Model Intercomparison
- Model Developments for the IPCC Fifth Assessment Report

GFDL's CM2.x Coupled Climate Models: Efforts in Support of the IPCC AR4 & the US CCSP

In 2004, following several years of intensive development efforts, a new family of GFDL climate models (the CM2.x family) was first used to conduct climate research.

The CM2.x models are being applied to decadal-to-centennial time scale issues (including multi-century control runs, climate of the 20th century simulations, & climate change projections), as well as to seasonal-to-interannual problems, such as El Niño research and forecasts.

GFDL CM2.x for the IPCC & CCSP

IPCC

(http://www.ipcc.ch)

WMO

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

UNEP

Every 5 or 6 years, an international group of scientists assemble a report documenting the state of scientific knowledge related to climate change. IPCC reports are ratified by ~180 member nations.

GFDL has been a prime player in the 3 previous assessment reports, and will be in the ongoing IPCC 4th Assessment Report (AR4) to be published in 2007. Two new global GFDL CM2.x climate models were developed for this purpose and for use in the US CCSP.

CCSP

US Climate Change Science Program
www.climatescience.gov

"best available science"

The US CCSP is a presidential initiative that seeks to integrate federal research on climate change. More than 20 synthesis & assessment reports on key topics relevant to decision makers are planned.

Code Development & Model Configuration

atmos

ocean

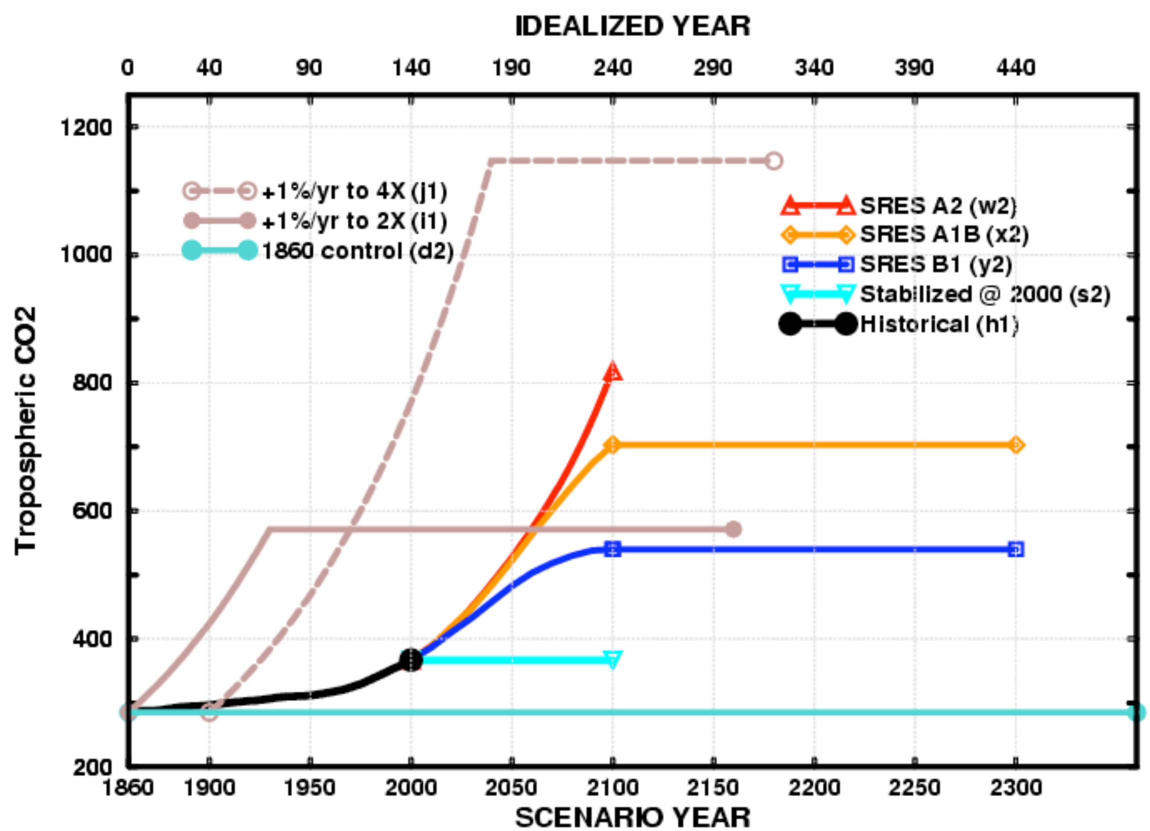
land

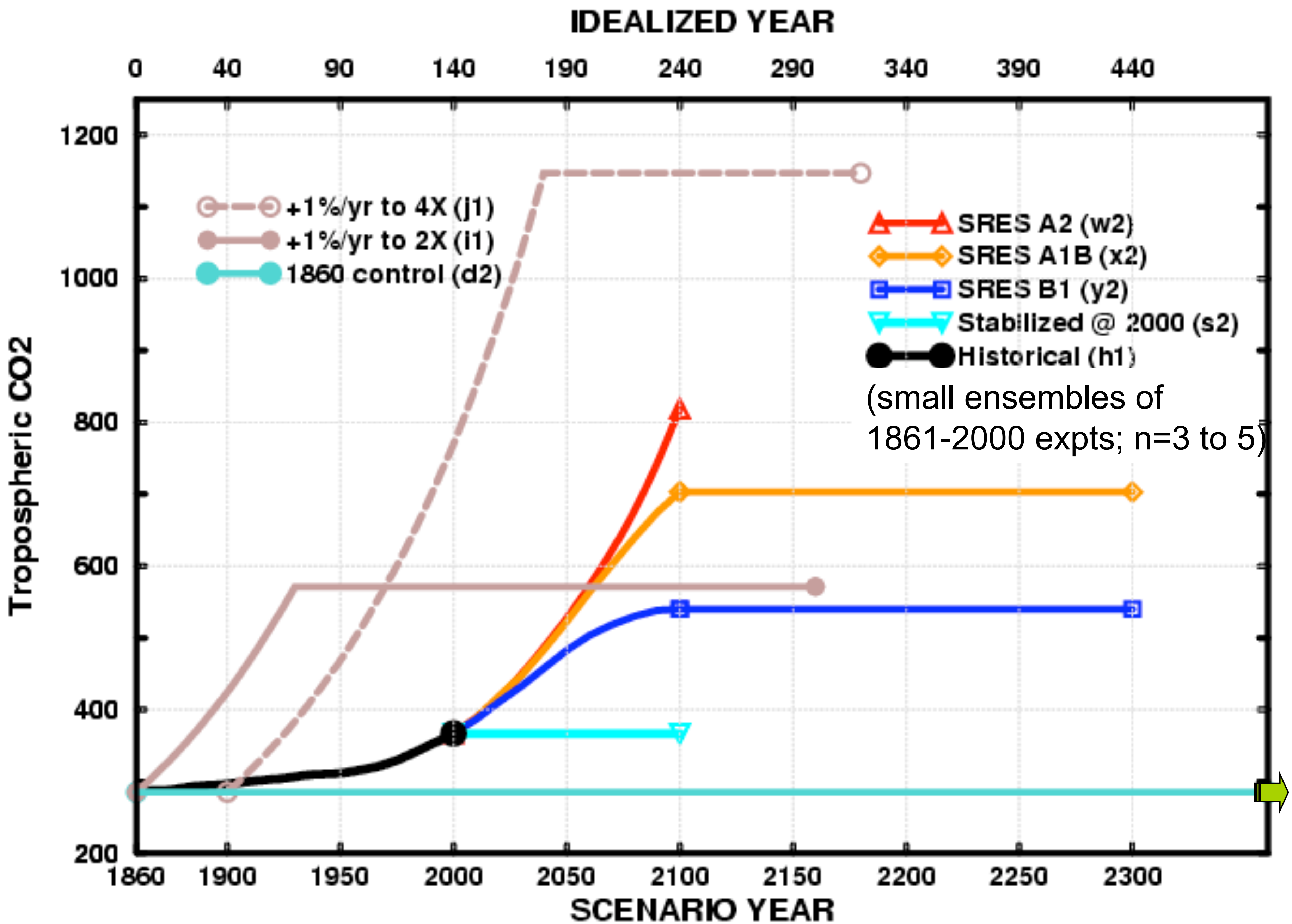
sea ice

CM2.0
dob: spring '04

CM2.1
dob: fall '04

In January 2004, the JSC/CLIVAR Working Group on Coupled Modeling (WGCM) requested that modeling centers run a set of ~10 experiments and make the model output available to IPCC WG 1 researchers.





IDEALIZED YEAR
0
40
90
140
190
240
290
340
390
440
1200
1000
800
600
400
200
Tropospheric CO2
+1%/yr to 4X (j1)
+1%/yr to 2X (i1)
1860 control (d2)
SRES A2 (w2)
SRES A1B (x2)
SRES B1 (y2)
Stabilized @ 2000 (s2)
Historical (h1)
(small ensembles of
1861-2000 expts; n=3 to 5)
1860
1900
1950
2000
2050
2100
2150
2200
2250
2300
SCENARIO YEAR

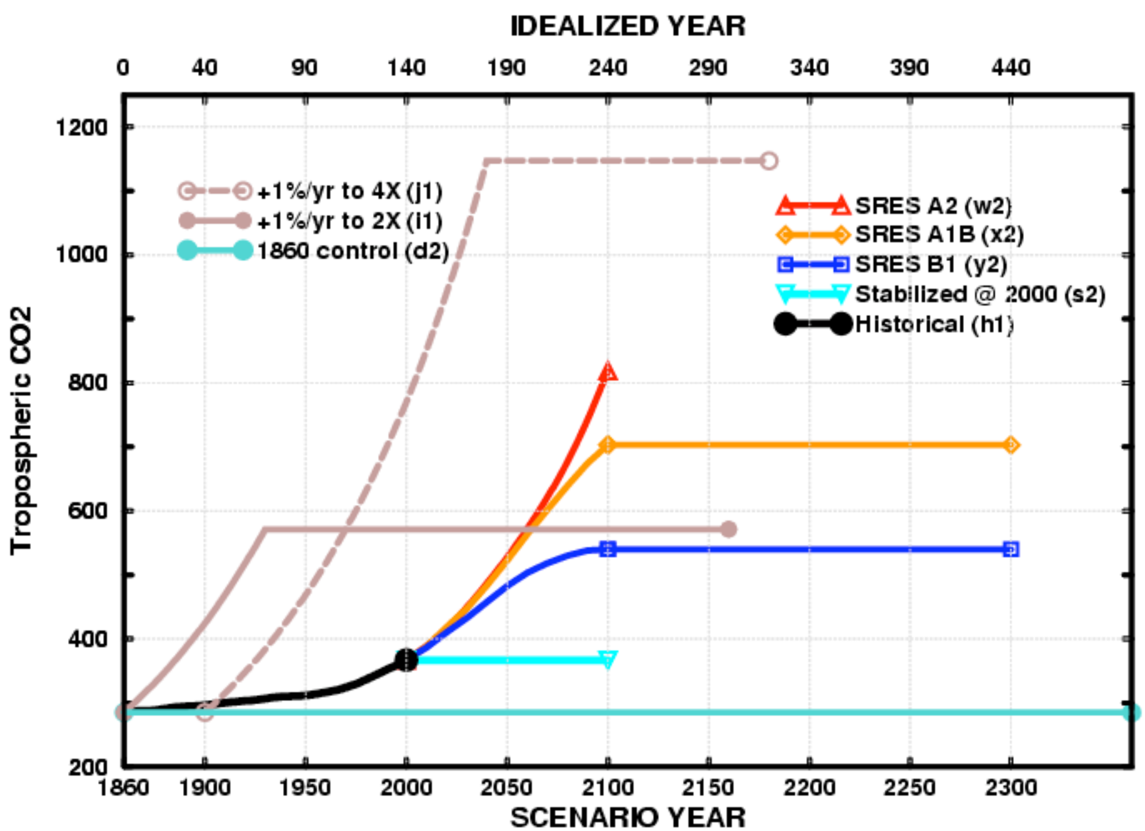
Code Development & Model Configuration

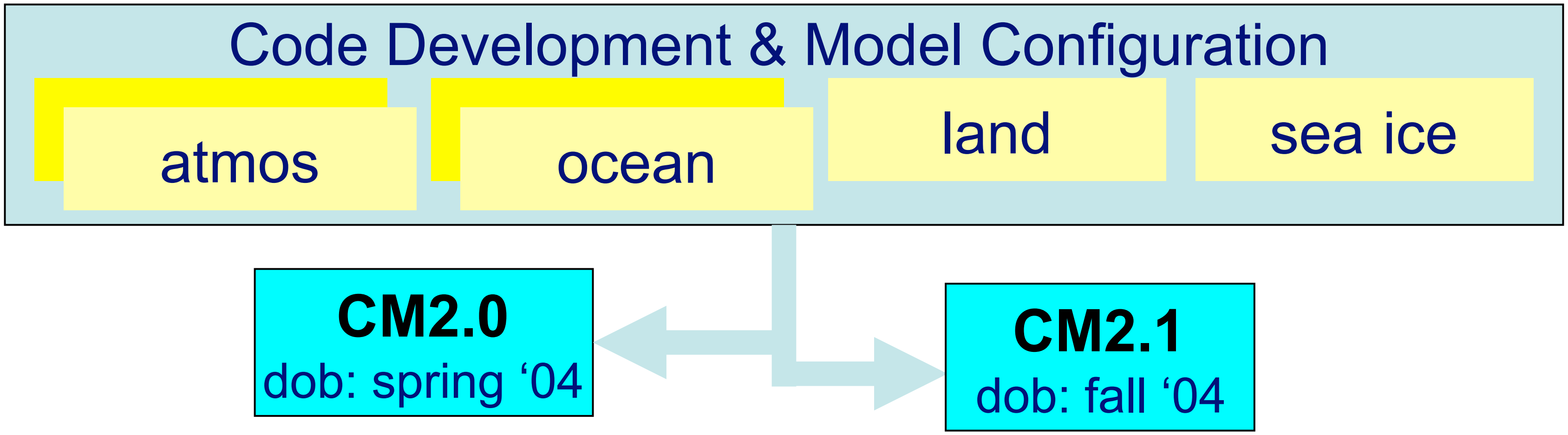
atmos | ocean | land | sea ice

CM2.0
dob: spring ‘04

CM2.1
dob: fall ‘04

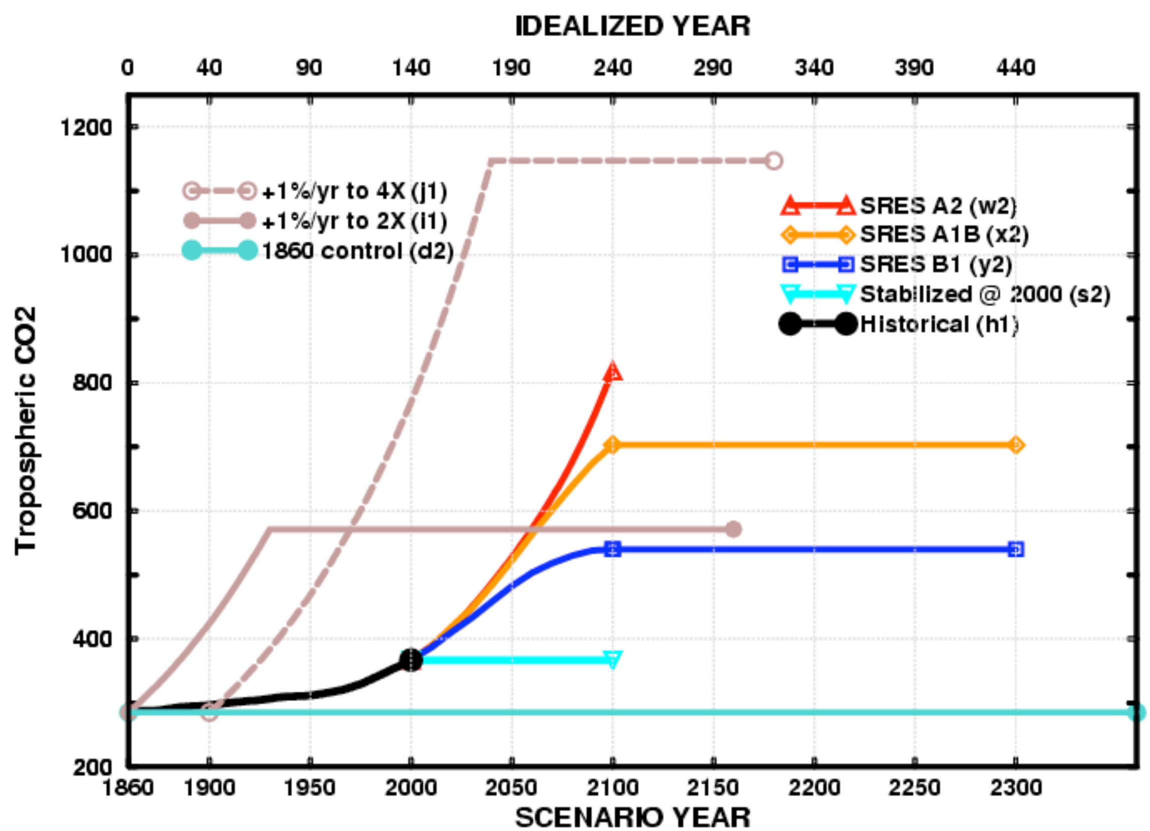
The models are computationally expensive. One CM2.1 job running 24 hours can integrate a simulation forward about 5 model years.
To complete a single 300 year long simulation requires the equivalent of running ~2 months using 60 processors of GFDL’s HPCS.

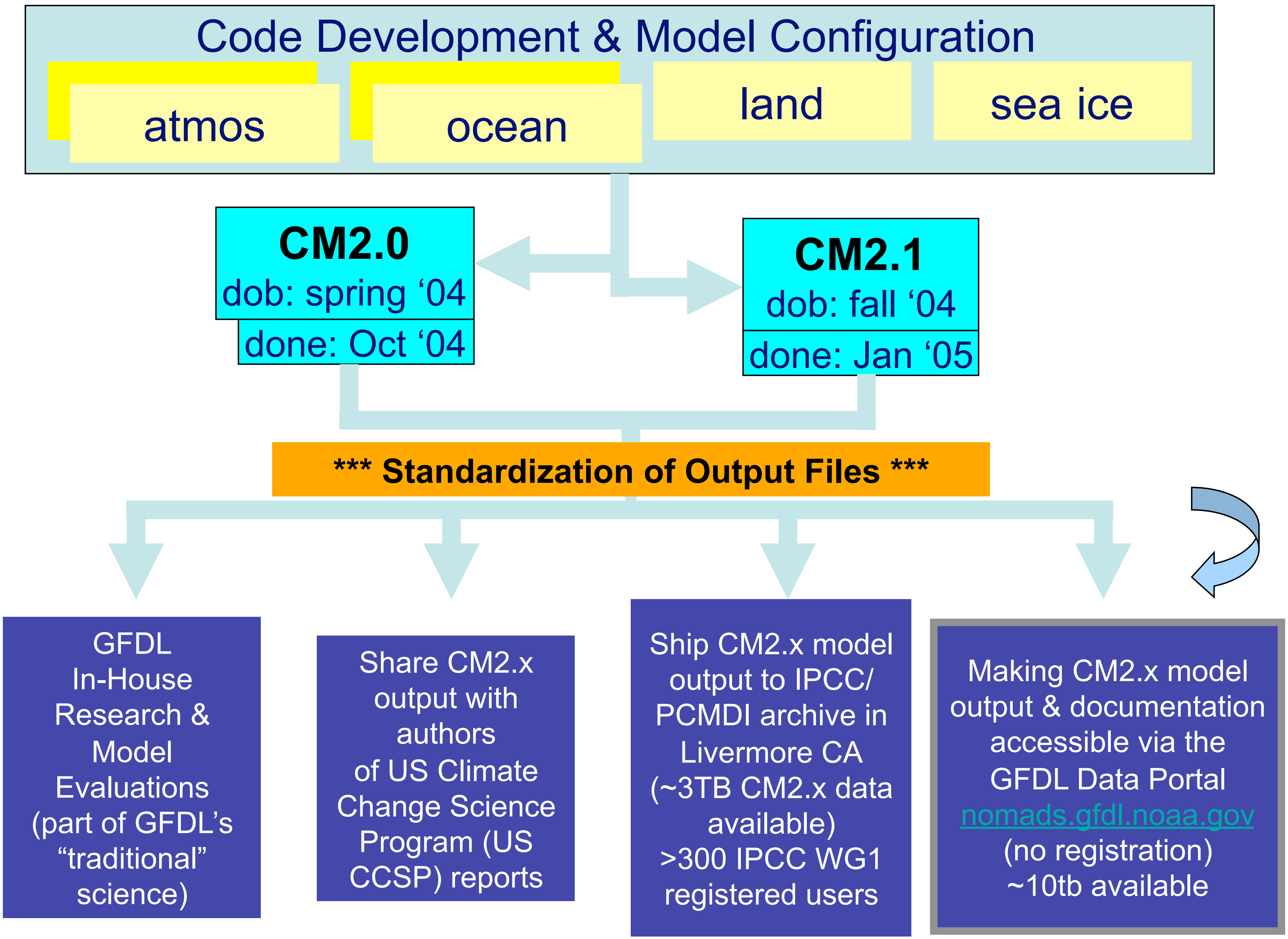




Each of the two sets of IPCC experiments represents ~2,600 model years of integrations.

The CM2.0 & CM2.1 experiments required 30% to 60% of GFDL's computing resources for ~12 months and generated >150 TB of model output files.




Code Development & Model Configuration
atmos
ocean
land
sea ice
CM2.0
dob: spring ‘04
done: Oct ‘04
CM2.1
dob: fall ‘04
done: Jan ‘05
*** Standardization of Output Files ***
GFDL In-House Research & Model Evaluations (part of GFDL’s “traditional” science)
Share CM2.x output with authors of US Climate Change Science Program (US CCSP) reports
Ship CM2.x model output to IPCC/ PCMDI archive in Livermore CA (~3TB CM2.x data available) >300 IPCC WG1 registered users
Making CM2.x model output & documentation accessible via the GFDL Data Portal nomads.gfdl.noaa.gov (no registration) ~10tb available

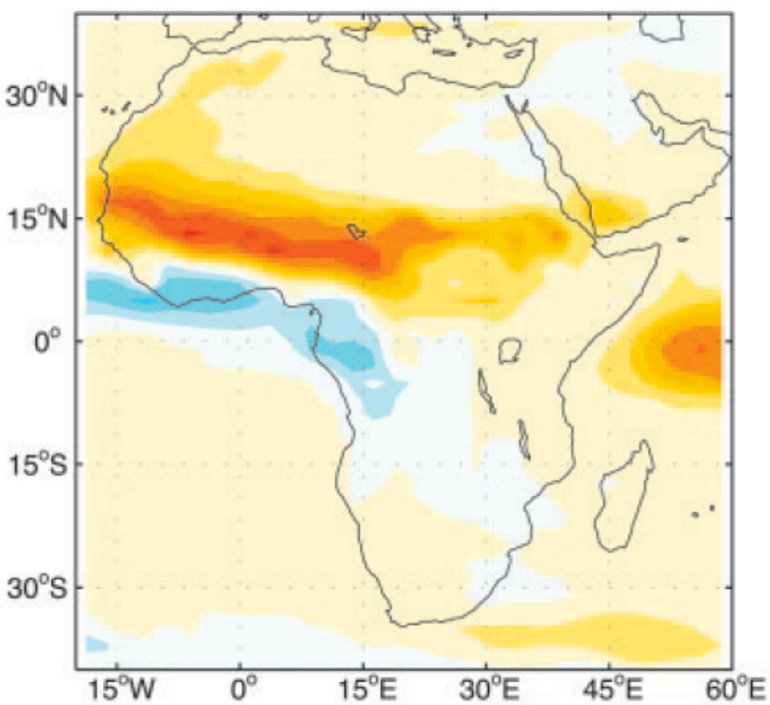
Examples of “traditional” GFDL work:

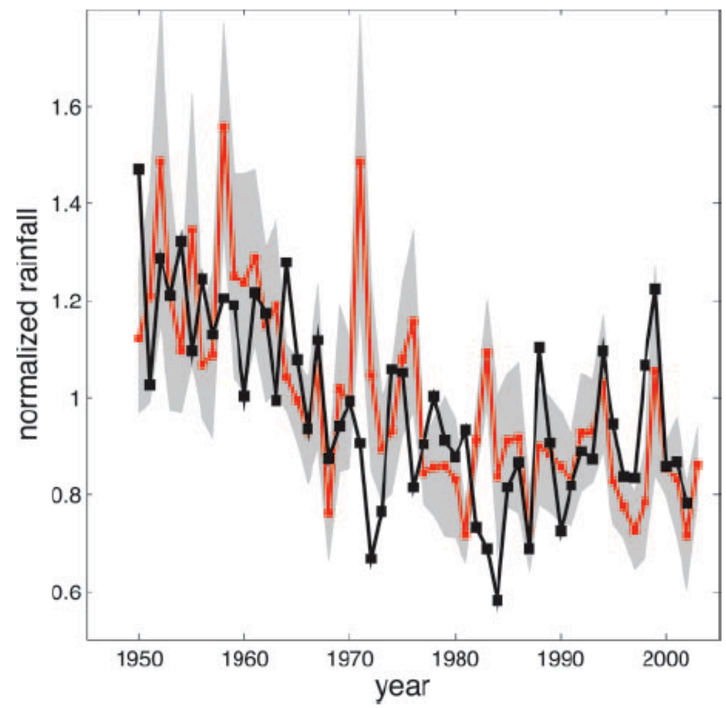
Increase scientific understanding; reduce uncertainties

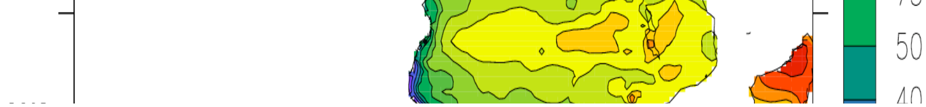
Simulation of Sahel drought in the 20th and 21st centuries

I. M. Held*†, T. L. Delworth*, J. Lu‡, K. L. Findell*, and T. R. Knutson*

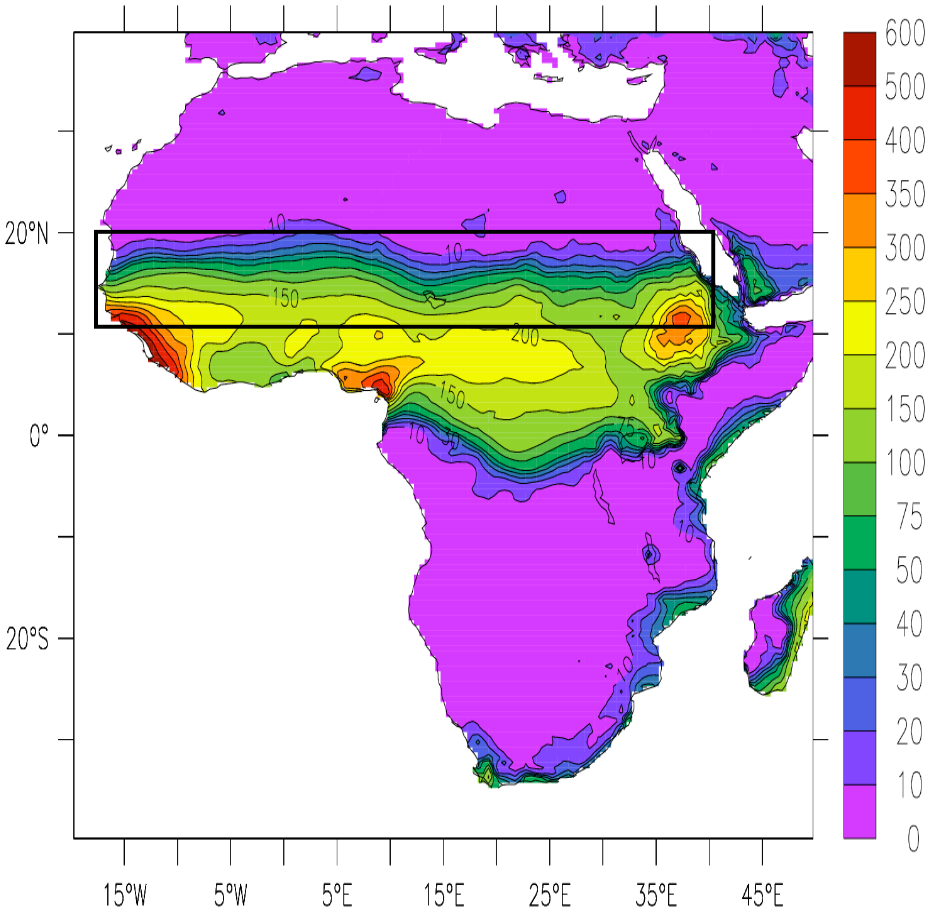
*Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration, ‡University Corporation for Atmospheric
P.O. Box 308, Princeton, NJ 08542

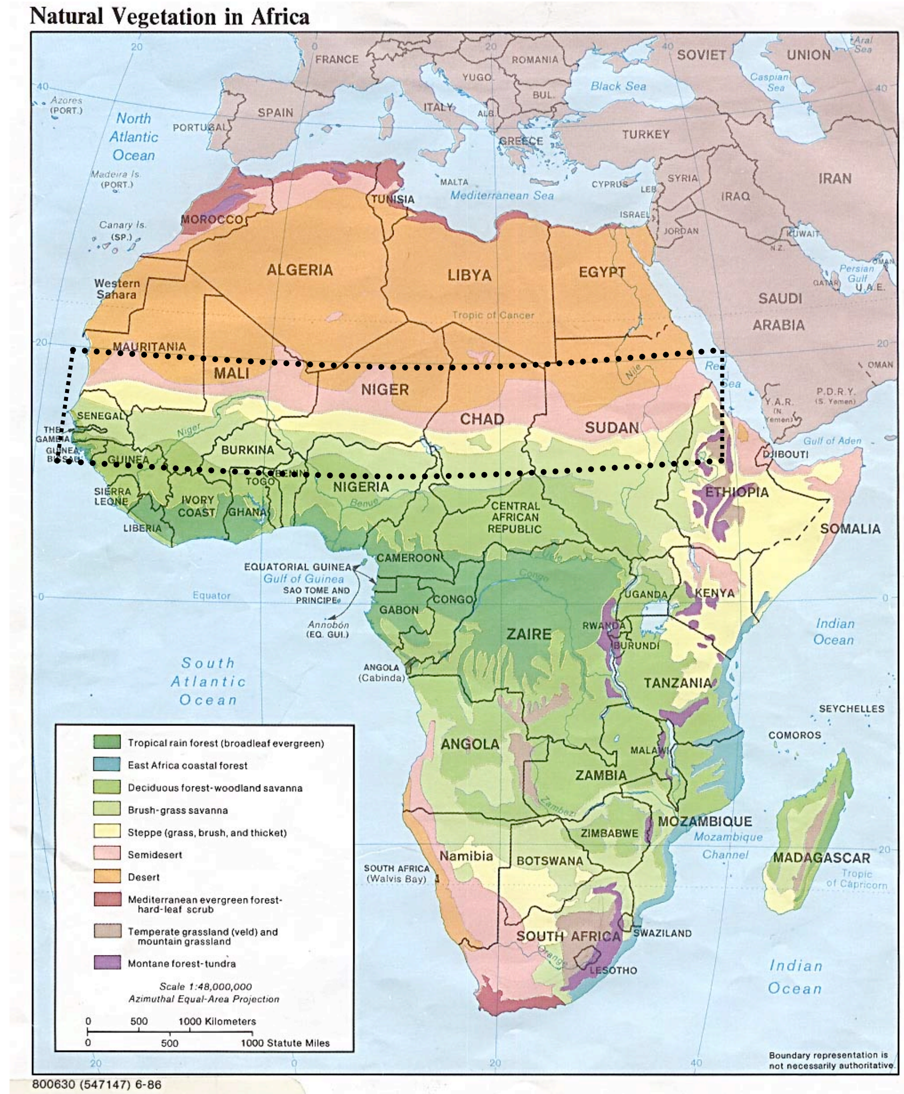






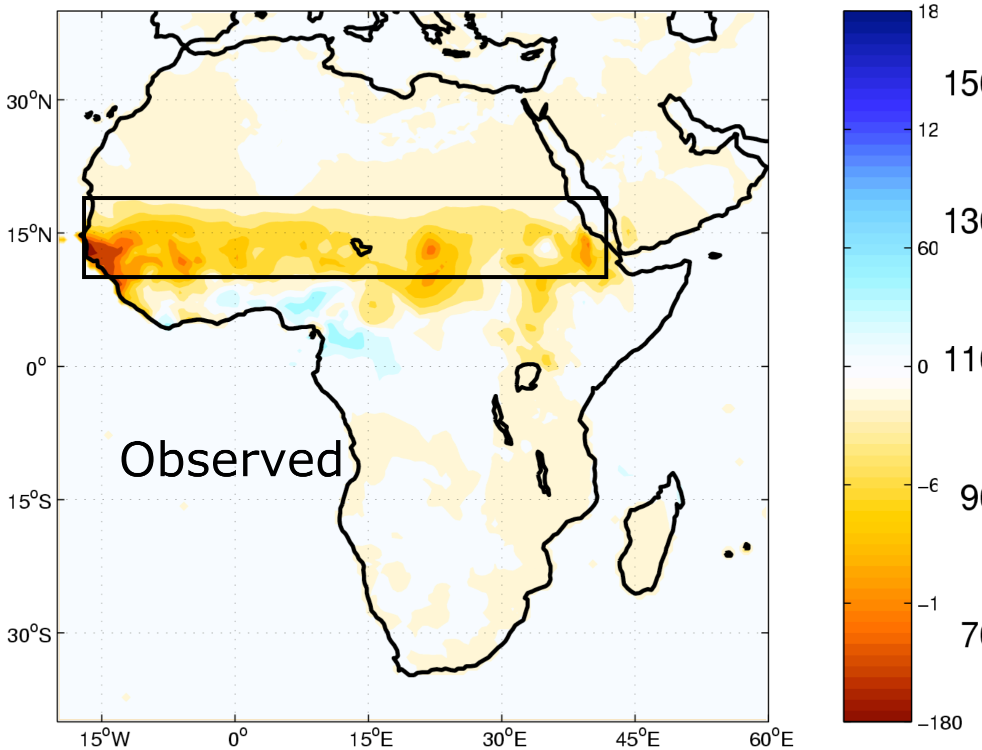
July Rainfall Climatology



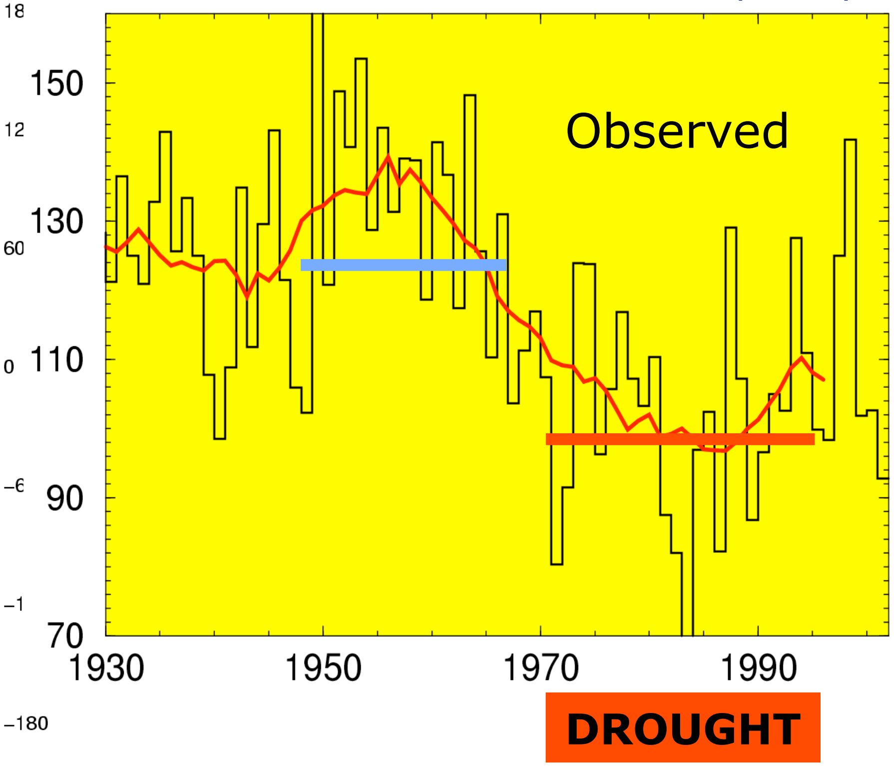


Observed late 20th century Sahel drought

1950-2000 trend (JAS)



Sahel rainfall time series (JAS)



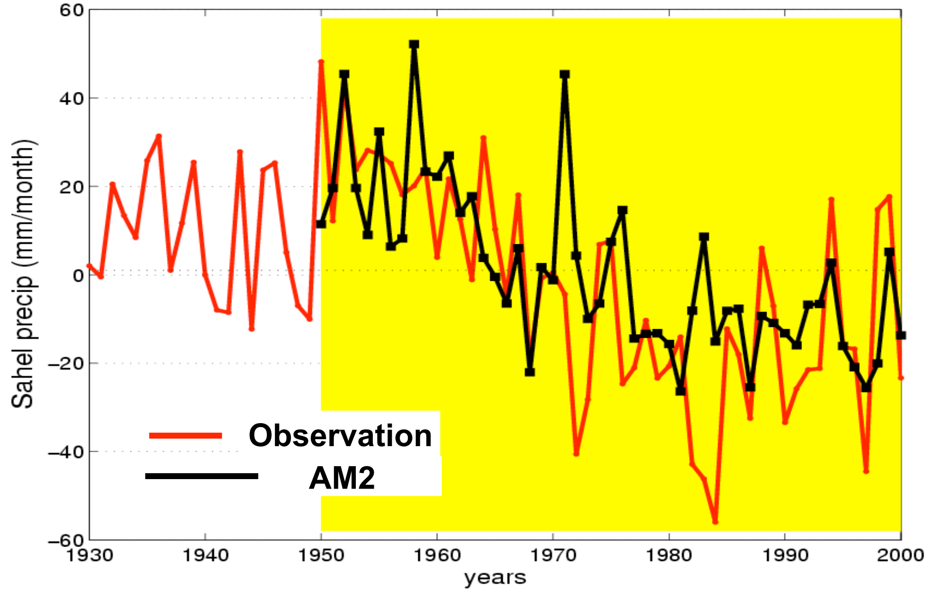
Causes of drought?

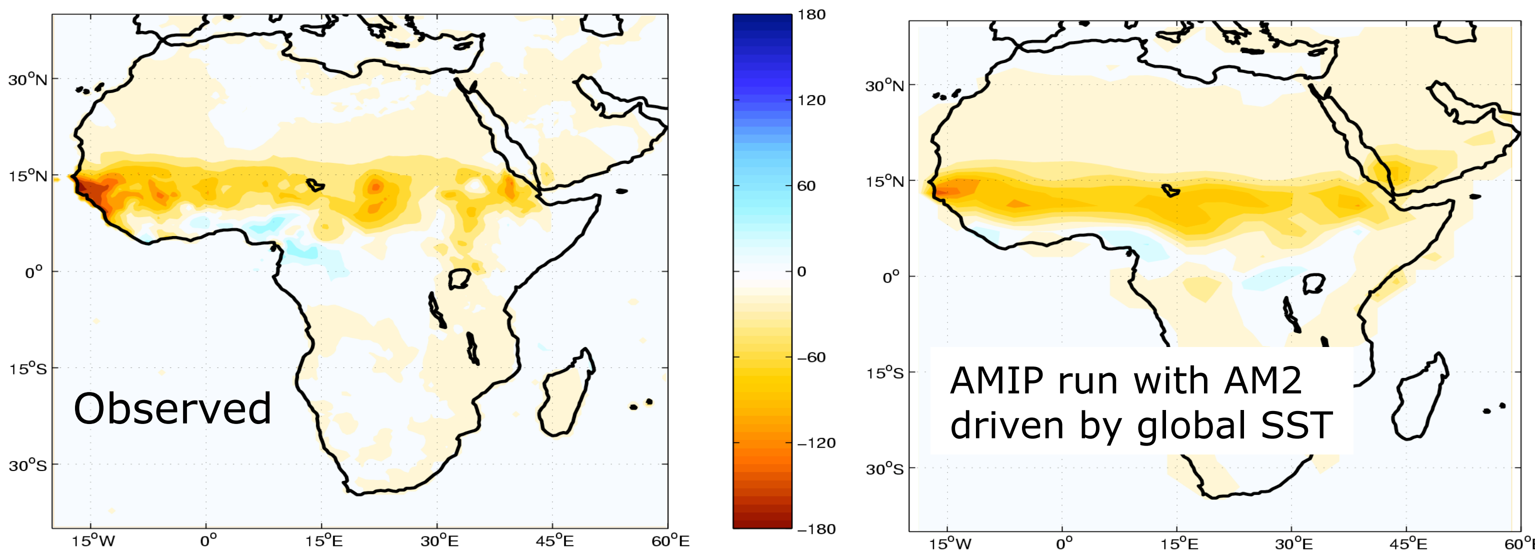
Local desertification

vs.

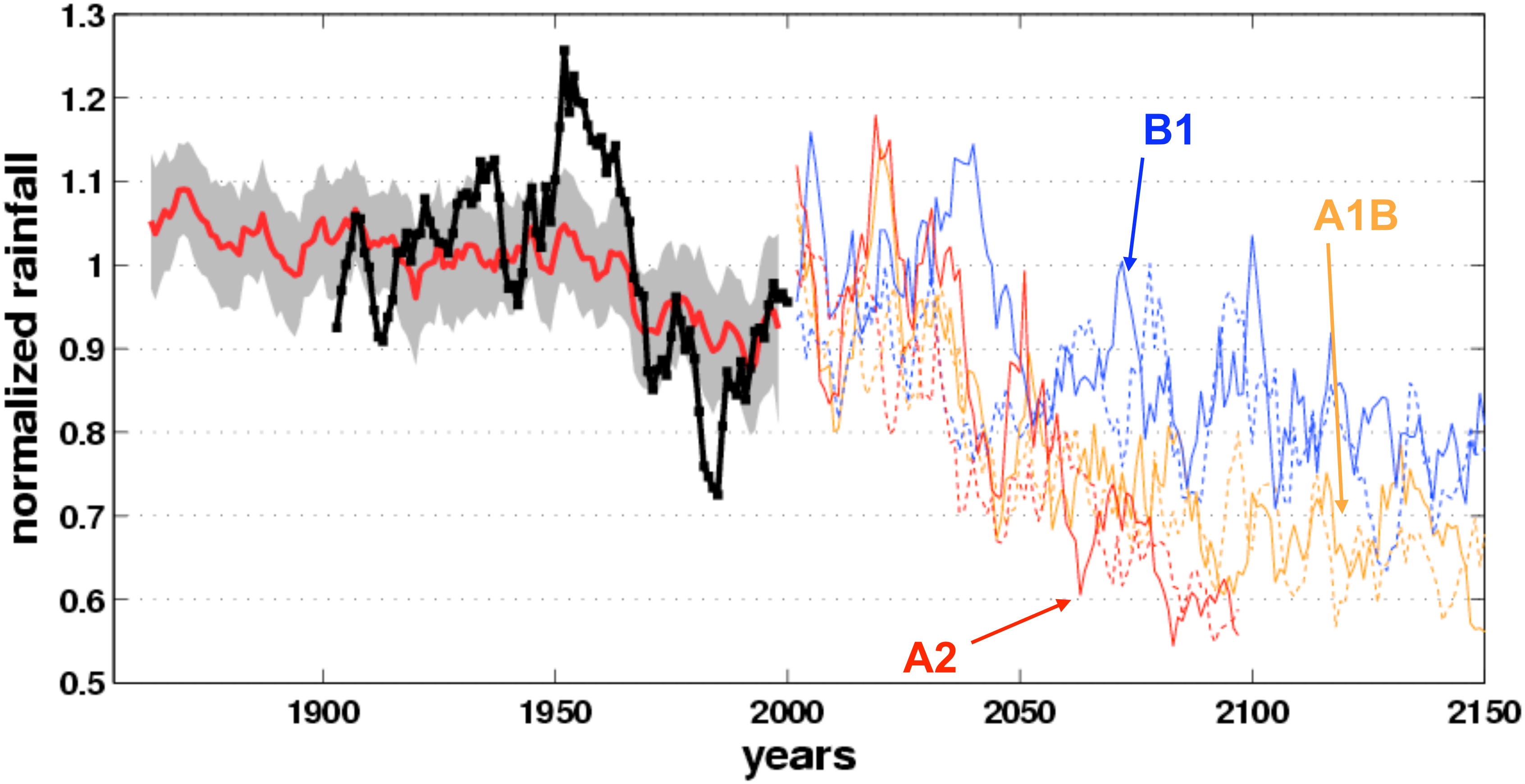
Large-scale ocean changes

1950-2000 trends in observed and simulated precipitation (JAS)



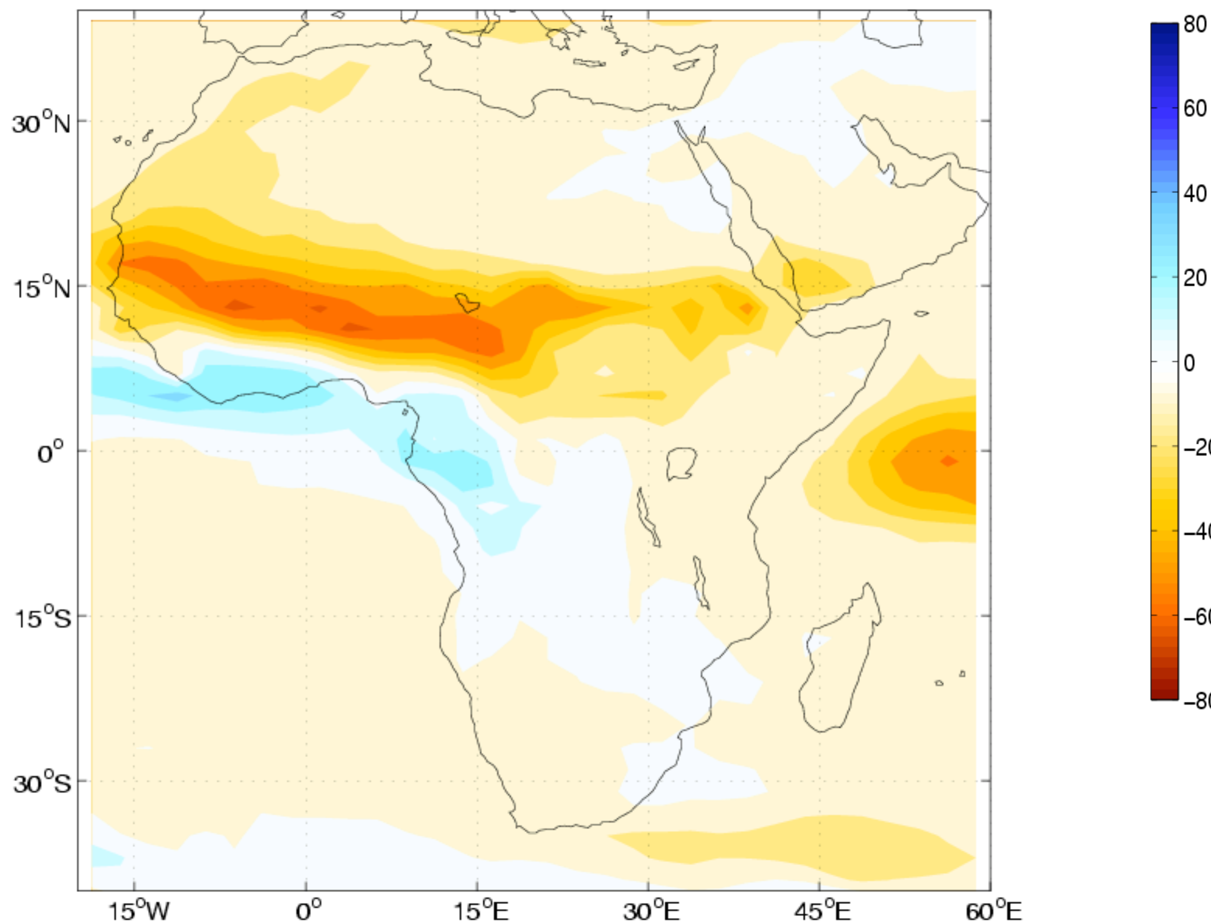


20th and 21st century Sahel rainfall in CM2



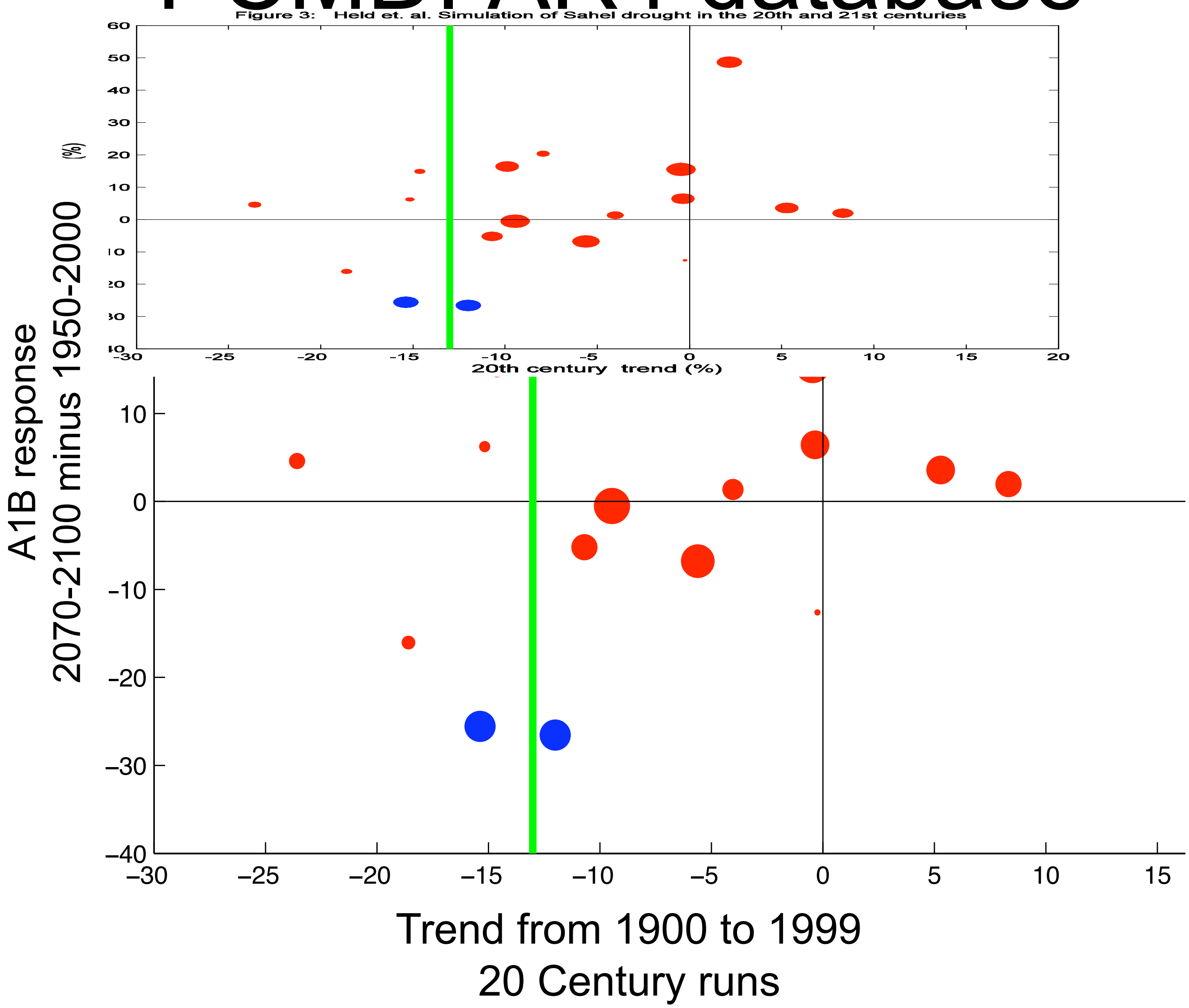
21st century Sahel rainfall in CM2

SRES A2
2081-2100
minus
present day



(CM2 mean)

18 models from the IPCC/ PCMDI AR4 database



Summary

- GFDL models (AM2, CM2) capture the late 20^{th} century Sahel drought. The drought simulated by the coupled model can largely be attributed to anthropogenic forcing: GHG and aerosols

- CM2 predicts further aridity in Sahel in the 21^{st} century, a scenario in concert with what is expected from the observed/simulated SST-Sahel rainfall relationship in the 20^{th} century;

A Note of Caution

“ **We advise against basing assessment of future climate change in the Sahel solely on the results from any model in isolation.**
… … …

In the interim, given the quality of CM2’s simulation of the spatial structure and time evolution of rainfall variations in the Sahel in the 20th century, we believe that its prediction of a dramatic future drying trend should be considered seriously as a possible future scenario. ”

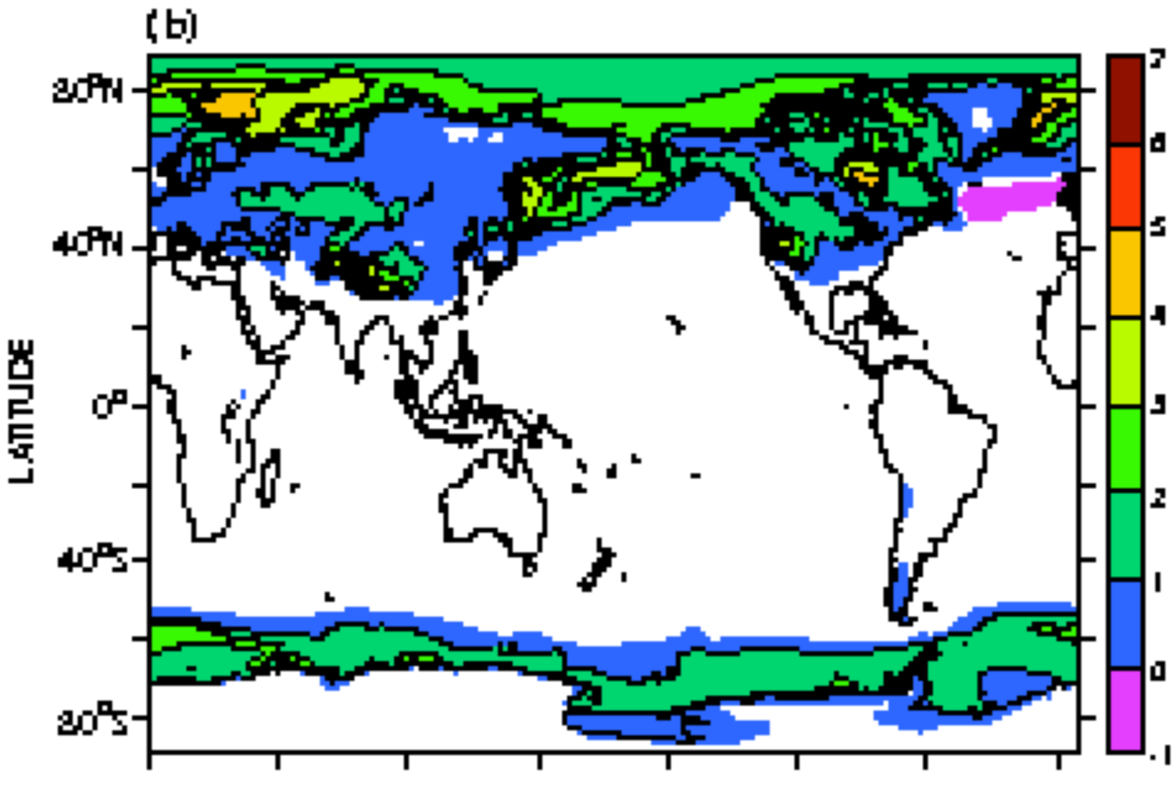
—— Held et al., 2005, PNAS

Examples of “traditional” GFDL work:

Increase scientific understanding; reduce uncertainties

Surface albedo feedbacks in GFDL and other IPCC AR4 models – M. Winton

Local contribution to global surface feedback (0.25 to 0.3) in 1% runs. Units (w/m**2 °K)



White means near 0.

In support of CCSP:

Reconciling models, radiosondes and satellites (MSU)

Amplification of Surface Temperature Trends and Variability in the Tropical Atmosphere

B. D. Santer,[1*] T. M. L. Wigley,[2] C. Mears,[3] F. J. Wentz,[3] S. A. Klein,[1] D. J. Seidel,[4] K. E. Taylor,[1] P. W. Thorne,[5] M. F. Wehner,[6] P. J. Gleckler,[1] J. S. Boyle,[1] W. D. Collins,[2] K. W. Dixon,[7] C. Doutriaux,[1] M. Free,[4] Q. Fu,[8] J. E. Hansen,[9] G. S. Jones,[5] R. Ruedy,[9] T. R. Karl,[10] J. R. Lanzante,[7] G. A. Meehl,[2] V. Ramaswamy,[7] G. Russell,[9] G. A. Schmidt[9]

The month-to-month variability of tropical temperatures is larger in the troposphere than at Earth's surface. This amplification behavior is similar in a range of observations and climate model simulations and is consistent with basic theory. On multidecadal time scales, tropospheric amplification of surface warming is a robust feature of model simulations, but it occurs in only one observational data set. Other observations show weak, or even negative, amplification. These results suggest either that different physical mechanisms control amplification processes on monthly and decadal time scales, and models fail to capture such behavior; or (more plausibly) that residual errors in several observational data sets used here affect their representation of long-term trends.

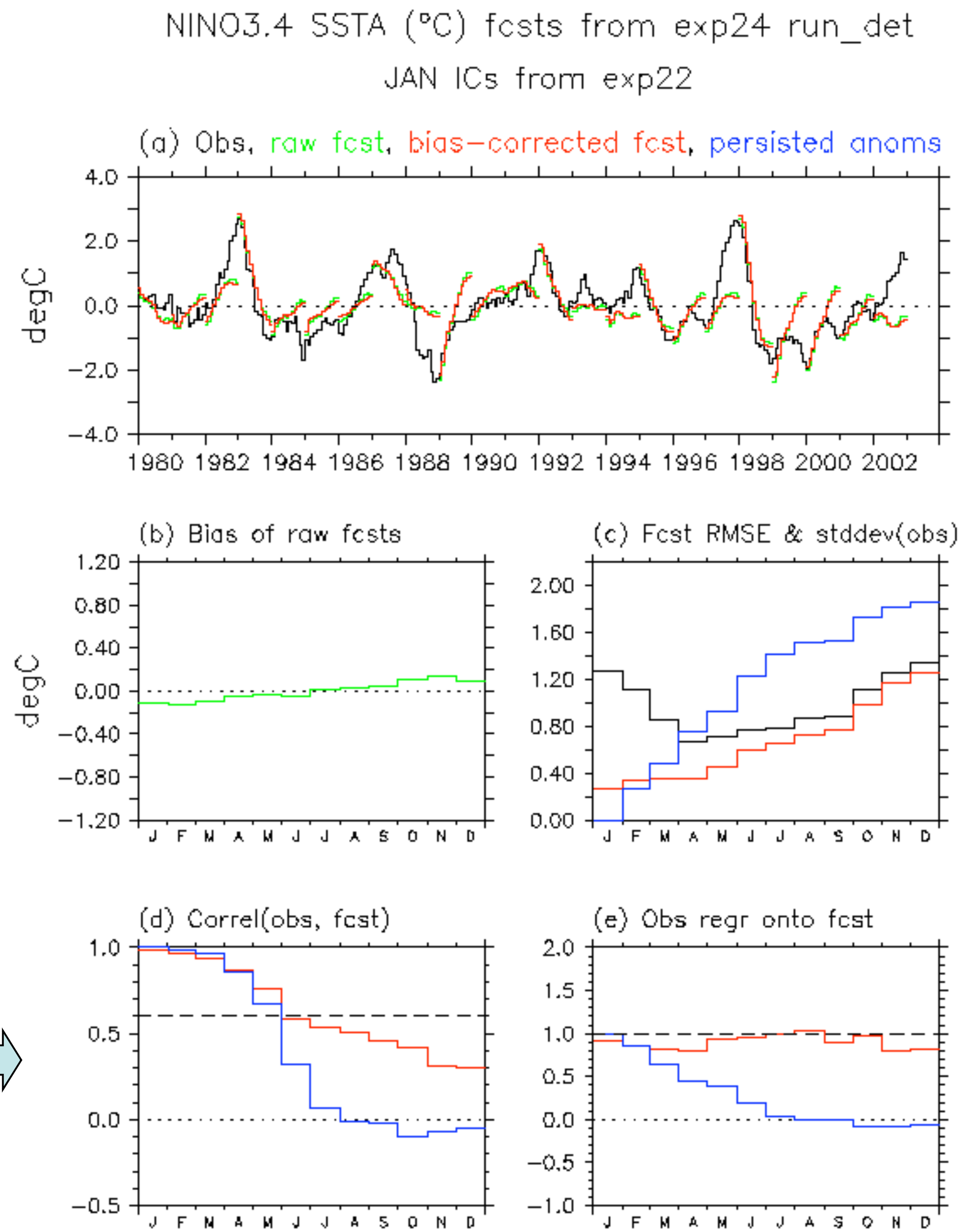
www.sciencemag.org SCIENCE VOL 309 2 SEPTEMBER 2005

SI Prediction

Forecasts started from each month (Jan. in this case).

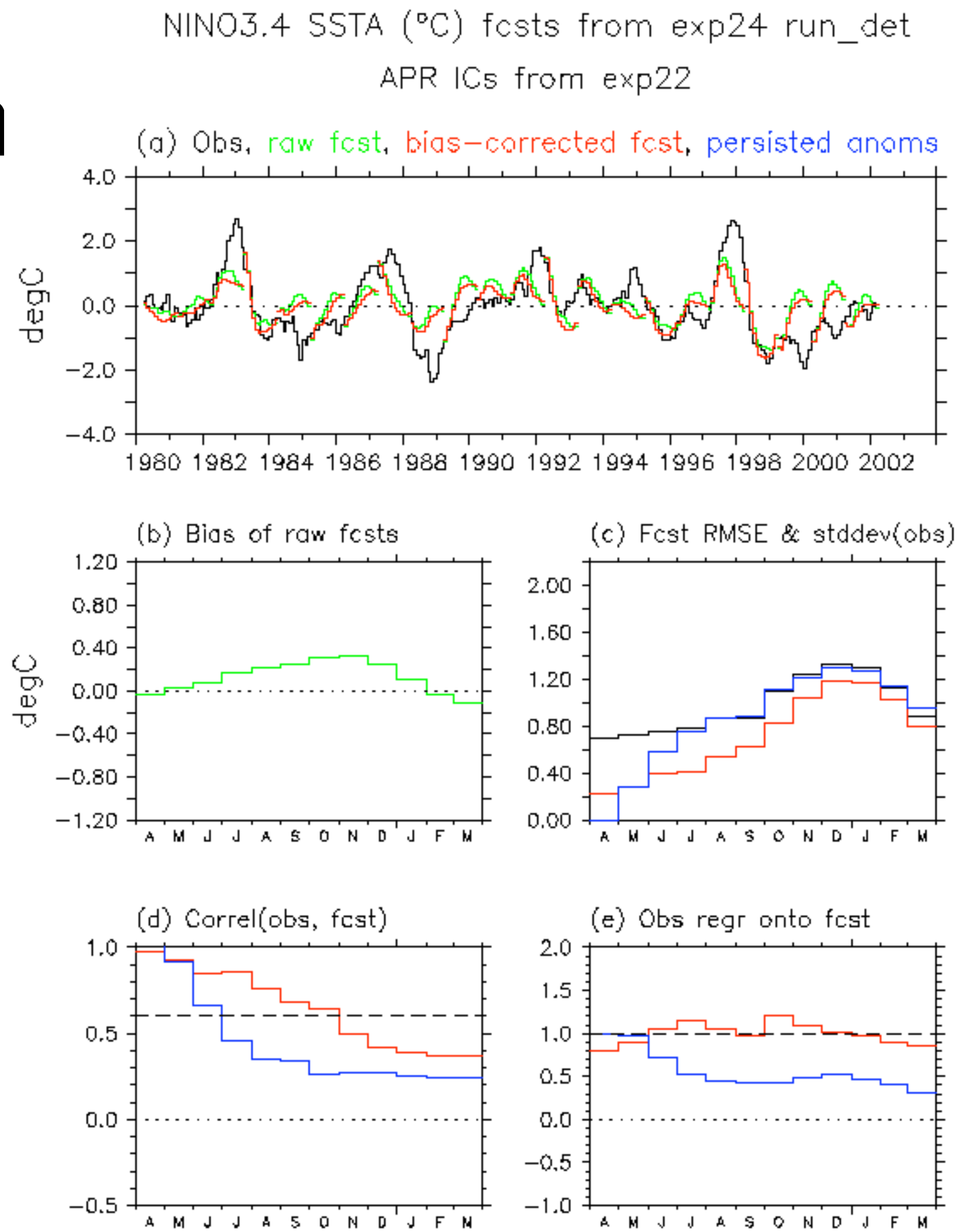
Bias of raw forecasts

Correlation of forecast with observations (red) vs. persistance (blue).



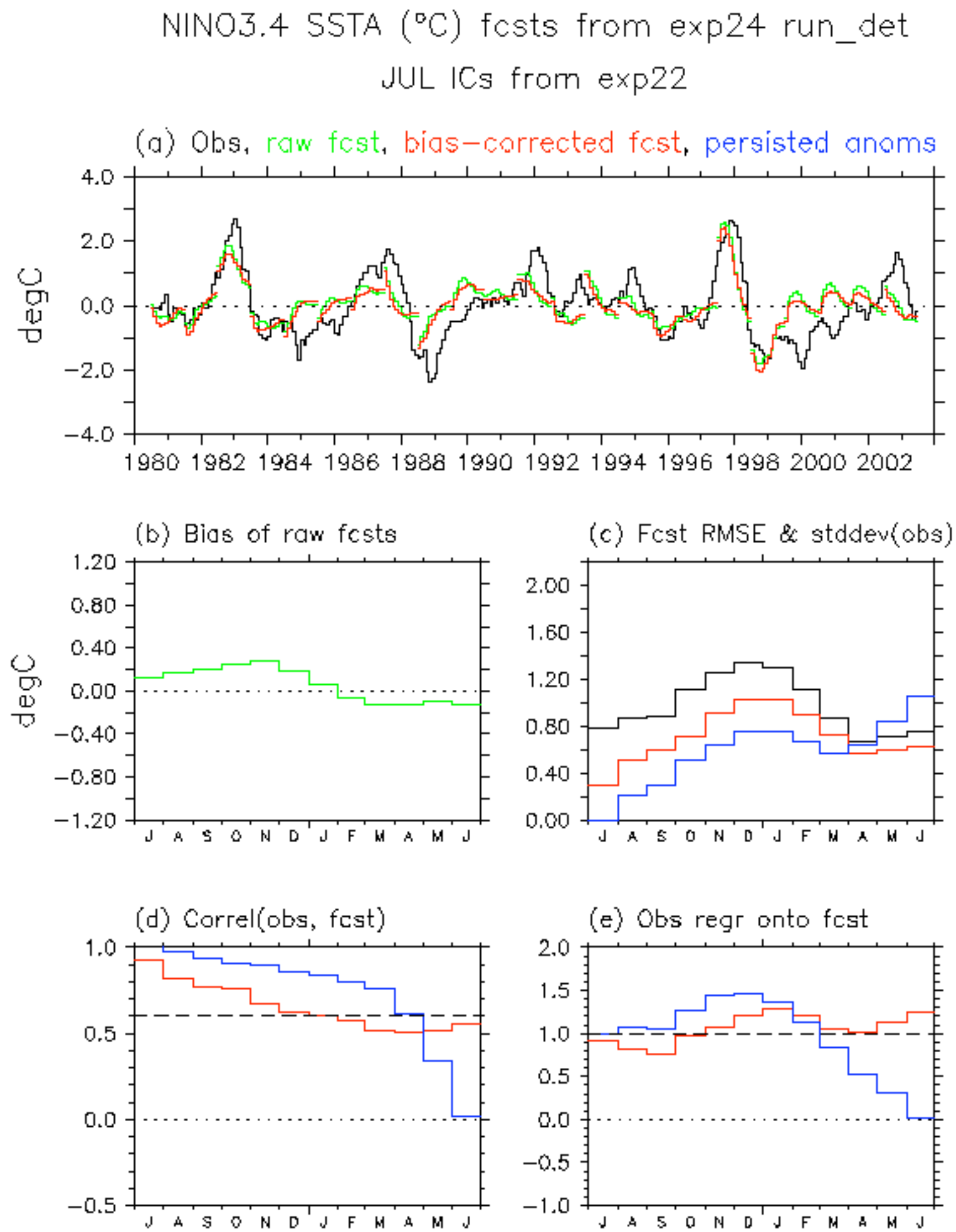
SI Prediction

April cases



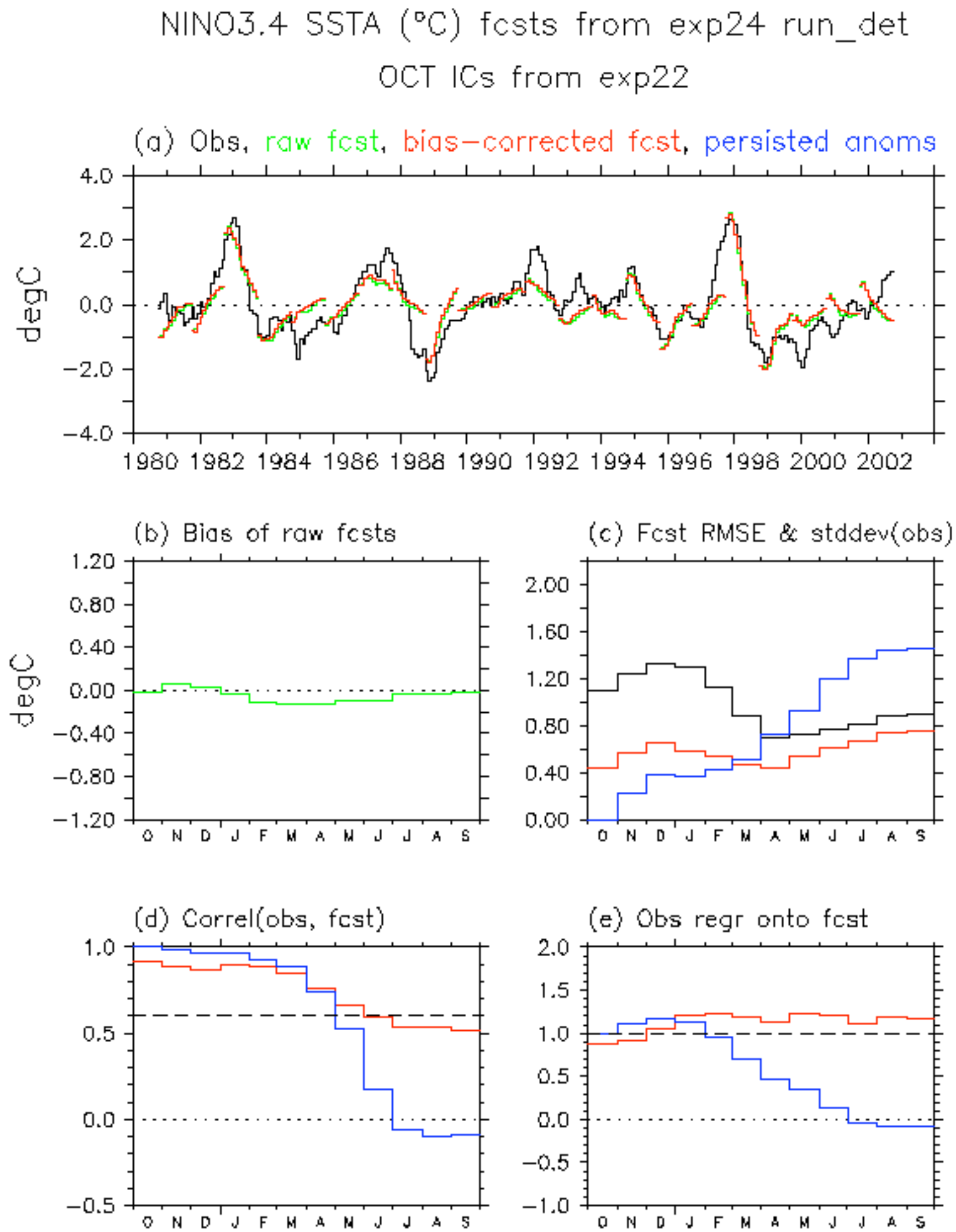
SI Prediction

July cases



SI Prediction

October cases



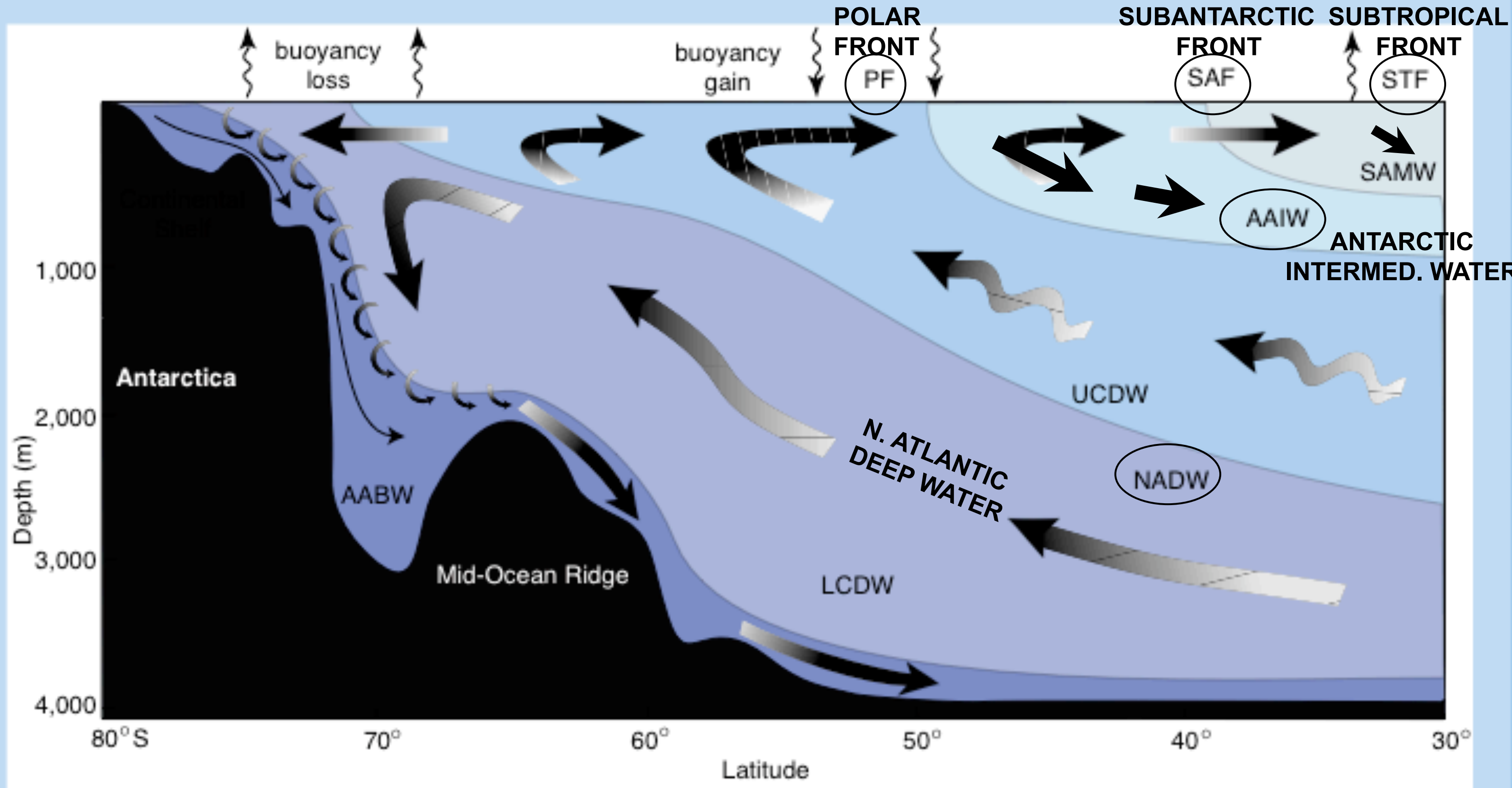
Summary

Model useful for SI prediction.

http://data1.gfdl.noaa.gov/~rgg/si_webpage_images/nino34.exp22.exp24_run_det.OCT.png

CM2 & Southern Ocean Divergence

Elements of the overturning circulation in the Southern Ocean



Schematic diagram of the overturning circulation in the Southern Ocean (Speer et al., 2000, J. Phys. Oceanogr., 30, 3212-3222).

AV/D5/0103

Southern Ocean Intercomparison

Model	ACC (Sv)	$d\rho/dy$	Total τ_x 10^{12}N	Max τ_x (N/m^2)	Latitude of Max τ_x
OBSERVED	**~135**	**0.58**	**6.5**	**0.161**	**52.4**
CSIRO-Mk3.0	336	0.85	7.8	0.207	51.3
GISS-ER	266	0.62	4.3	0.107	46.0
UKMO-HadCM3	223	0.97	6.4	0.163	51.3
GISS-AOM	202	0.38	2.9	0.166	43.5
UKMO-HadGEM1	199	0.65	7.1	0.190	52.5
MIROC3.2(medres)	190	0.43	5.3	0.184	46.0
GFDL-CM2.1	**135**	**0.58**	**6.1**	**0.162**	**51.0**
MIROC3.2(hires)	125	0.49	6.3	0.175	46.5
GFDL-CM2.0	**113**	**0.56**	**4.5**	**0.149**	**46.0**
CCCMA-CGCM3.1(T63)	106	0.43	7.2	0.192	48.8
BCCR-BCM2.0	105	0.53	NA	NA	48.8
MRI-CGCM2.3.2a	94	0.40	5.6	0.157	48.8
CCCMA-CGCM3.1(T47)	93	0.27	5.9	0.180	46.4
INM-CM3.0	80	0.71	6.0	0.172	48.0
IAP-FGOALS1.0g	75	0.39	4.8	0.138	48.8
CNRM-CM3	54	0.31	2.4	0.106	46.0
IPSL-CM4	34	0.18	2.7	0.160	41.8
GISS-EH	-6	0.43	3.6	0.096	46.0

Framework to consider S. Ocean simulation
(things to get "right")

- Strength of westerlies over Drake Passage latitudes.
- Surface buoyancy fluxes around Antarctica.
- T,S properties and volume of modeled NADW in southern Atlantic.
- Latitude & strength of maximum S.H. westerlies.

The uptake of heat and carbon by the ocean is greatly affected by the Southern Ocean, where much water mass transformation occurs. Large scale patterns of surface climate change also are influenced by these processes.

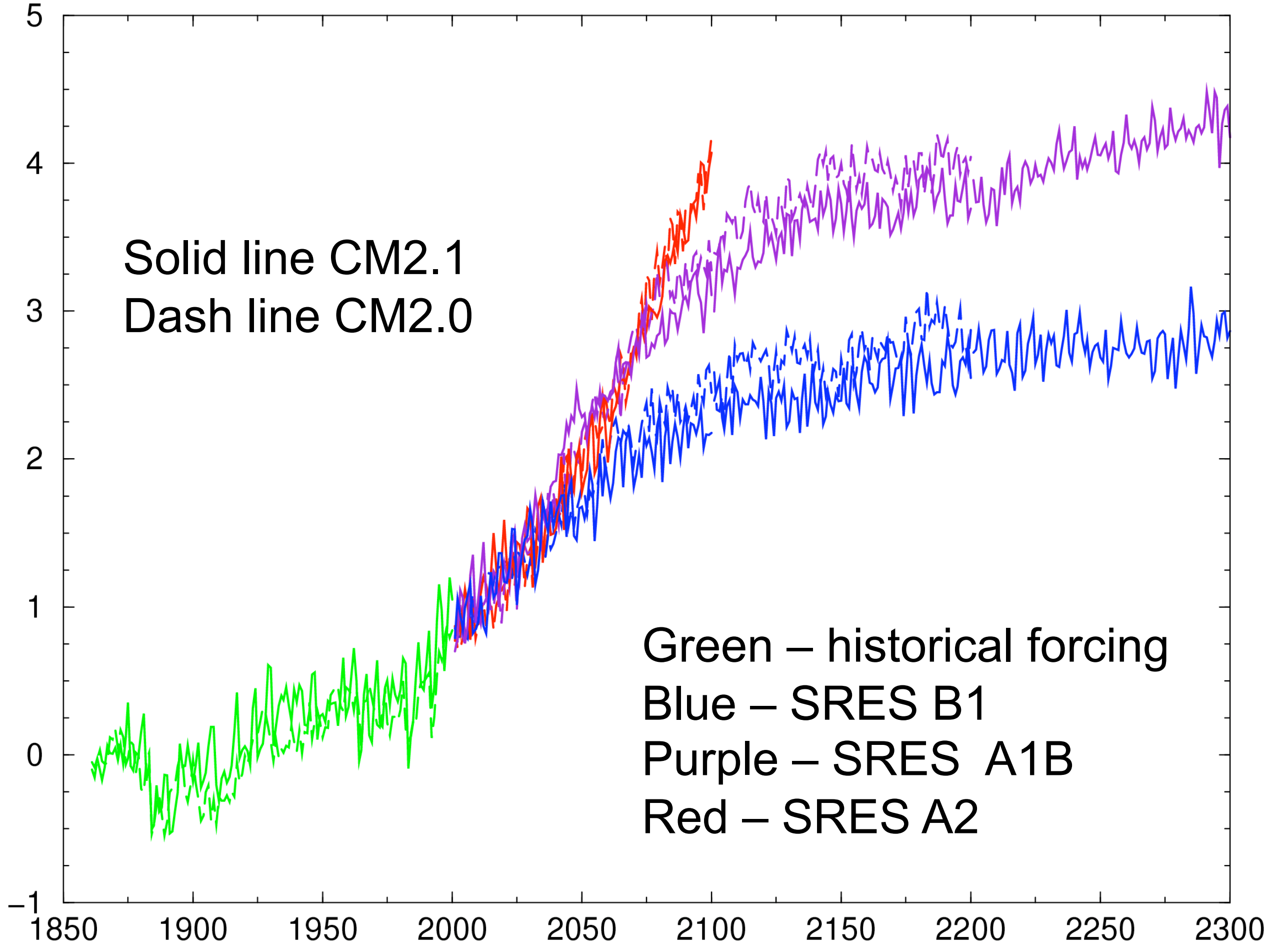
This framework helps one categorize and analyze coupled climate model simulations of the Southern Ocean.

Getting the Southern Ocean "right" – So What?

- Big impact on transient climate response
- Heat uptake
  - More heat uptake reduces SAT response
  - More heat uptake increases sea level rise
- Carbon and other tracer uptake
  - More carbon uptake reduces SAT response
  - More carbon uptake makes water more alkaline

Importance of Southern simulation

CM2.0 has larger transient climate response in spite of smaller climate sensitivity (2.9K vs 3.4K).



Looking ahead to IPCC AR5

In going from the previous generation of GFDL global coupled climate models to the current CM2 models we …

- improved model resolution (ocean & atmosphere, horizontal & vertical)
- developed more sophisticated physical parameterizations in all model components & included more radiative forcing agents
- abandoned flux adjustments
- implemented better numerics
- enhanced on-line diagnostics, etc.

…always mindful of resource constraints.

2 Critical Resources:
People with Expertise & Computers
(requires both Brain Power & Compute Power)

Looking ahead to IPCC AR5

The next generation of GFDL coupled climate models may include…

- improvements in model resolution (vertical & horizontal)*
- more sophisticated treatment of biogeochemical processes (toward a more complete Earth system model)*
- continued development of physical parameterizations, treatment of radiative forcing agents, etc.
- Consideration of different model components (ocean, atmosphere, land surface, sea ice)

*(computer intensive)

…still, always mindful of resource constraints.

Given computer resources, we need to be able to integrate *X* model years within *Y* calendar months.

Summary

- GFDL continuing its efforts to develop state of the art climate models.
- GFDL successful in its model develop efforts for AR4 and other activities.
- A huge amount of resources (people, computer, storage) needed to support this effort.
- Conflicting directions for next model
  - Resolution
  - Ensemble members
  - Additional components (geo-bio-chemistry)